INFLUENCE OF PENETRATION FORCE IN CLAY SOILS DUE TO SPEED RATE EFFECT

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Special for:

Beloved Mom and Dad

Rahaidah Taib and Ayob Awang Kechik

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ABSTRACT

This research discusses the effects of penetration rate on the penetration resistance in clayey soils for five different speeds of penetrations. In order to install the pile through hydraulic system, it is crucial to understand the required penetration force needed to do the job. Generally, the penetration force and speed will be different for different soil conditions. Proper understanding of this scenario may facilitate the engineer to mobilize the suitable pile installer to the construction site. Therefore, this study are to determine the influence of pile installation force in clay by conducting field cone penetration test (CPT) over a range of rates 0.5 cm/s, 1cm/s, 2cm/s, 2.5cm/s and 5cm/s. A total of fifteen point cone penetration test were conducted to determine the behaviour of the clayey soils under the different penetration loading rates. Results show that the speed for 0.5 cm/s and 1 cm/s is more accurate and more consistent compared to 2 cm/s, 2.5 cm/s and 5 cm/s. This is because with lower speed, the test becomes easier to control unlike higher speed. Besides that, maximum strength was achieved when test reach to standard speed of penetration and reducing when the rate exceeds the 2.5 cm/s speed. These findings may serve a wide range of industrial applications whereby require the solution of time domain problems and an associated understanding of rate effects in clay soils. Then, a relationship between speeds of penetration with shear strength was determined.

Keyword: Speed of penetrations, cone penetration test, rate effect, shear strength

ABSTRAK

Penyelidikan ini membincangkan kesan kadar penembusan pada rintangan penembusan dalam tanah liat selama lima kelajuan yang berbeza penembusan. Untuk memasang cerucuk melalui sistem hidraulik, ia adalah penting untuk memahami kuasa penembusan yang diperlukan diperlukan untuk melakukan pekerjaan itu. Secara umumnya, daya penembusan dan kelajuan akan berbeza untuk keadaan tanah yang berbeza. pemahaman yang betul tentang senario ini boleh memudahkan jurutera untuk menggerakkan pemasang cerucuk yang sesuai untuk tapak pembinaan. Oleh itu, kajian ini adalah untuk menentukan pengaruh daya pemasangan cerucuk dalam tanah liat dengan menjalankan bidang ujian penembusan kon (CPT) atas pelbagai kadar 0.5 cm/s, 1 cm/s, 2 cm/s, 2.5 cm/s dan 5 cm/s . Sebanyak lima belas titik ujian penembusan kon telah dijalankan bagi menentukan kelakuan tanah liat di bawah kadar penembusan loading berbeza. Hasil dari ujikaji menunjukkan kelajuan untuk 0.5 cm/s dan 1 cm/s lebih tepat dan konsisten berbanding 2 cm/s, 2.5 cm/s dan 5 cm/s. Ini kerana dengan halaju yang rendah, ujikaji lebih terkawal berbanding halaju tinggi. Selain itu, kekuatan tertinggi telah dicapai ketika ujian berada pada kelajuan piawai dan menurun ketika kadar melebihi 2.5 cm/s. Penemuan ini boleh membantu pelbagai aplikasi industri yang mana memerlukan penyelesaian masalah domain masa dan pemahaman berkaitan kesan kadar dalam tanah liat. Hubungan antara kelajuan penembusan dengan kekuatan ricih telah ditemui.

Kata-kunci: Kelajuan penembusan, ujian penembusan kon, kesan kadar, kekuatan ricih

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LIST OF SYMBOLS AND ABBREVIATIONS

A_s	-	Surface area of the sleeve
c	-	Cohesion
C_c	-	coefficients of curvature
cm	-	centimetre
C_u	-	values of uniformity
D	-	diameter
D_{10}	-	The particle sizes corresponding to 10% passing value of sieve
D_{30}	-	The particle sizes corresponding to 30% passing value of sieve
D_{60}	-	The particle sizes corresponding to 60% passing value of sieve
F_c	-	Total force acting on cone tip
F_r	-	Friction ratio
f_s	-	Sleeve friction
ft.	-	feet
g	-	gram
in.	-	Inch
kg	-	kilogram
kN	-	kilonewton
kPa	-	kilopascal
m	-	metre
mm	-	milimetre
MPa	-	megapascal
N	-	Newton
q_c	-	Cone resistance
q_t	-	Total cone resistance
R^2/ r^2	-	coefficient of determination
s	-	second

St	-	Sensitivity
u	-	Pore water pressure
V_s	-	Shear Wave Velocity
w	-	moisture content
ASD	-	Allowable Stress Designs
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CAD	-	Computer Aided Design
CPT	-	Cone Penetration Test
CRP test	-	Constant Rate of Penetration Test
DCP	-	Dynamic Cone Penetrometer
DOTD	-	The Louisiana Department of Transportation and Development
IRTP	-	International Reference Test Procedure
LRFD	-	Resistance Factor Designs
OC	-	Organic content
PL	-	Plastic limit
QM test	-	Quick Maintained Load Test
RECESS	-	Research Centre for Soft Soil
SBT	-	Soil Behaviour Test
SI	-	Site investigation
SL	-	Shrinkage limit
SM test	-	Maintain Load Test
SM test	-	Slow Maintained Pile Load Test
SS	-	Steel Sheet

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Cone penetration test (CPT) is one of the methods that widely used for soil investigation in around the world. CPT has been routinely used as a site investigation tool. Almost 75 years, CPT widely used as a common method for obtaining soils information in Europe and CPT is now recognized throughout the world as a viable method of obtaining soils classifications. The accuracy and detailed nature of CPT data become the principal reasons for acceptance and increased use of the CPT in recent years, the fact that the test conducted is in-situ by eliminating sample disturbance and changed stress conditions, and the relative speed and economy of the method as compared to conventional drilling and sampling (Yilmaz, 2013).

Site investigations for exploring soils and soft ground for support of embankments, retaining walls, pavement subgrades, and bridge foundations can be solved by using CPT since it is a fast and reliable. The CPT soundings can be used either as a replacement or complement to conventional rotary drilling and sampling methods. In CPT, there are electronic steel probes which are hydraulically pushed to soils that can collect continuous readings of point load, friction, and pore water pressures with typical depths up to 30 meters (100 feet) or more reached in about 1 to 1½ hours due to their rate of speed. The geostratigraphy, soil types, water table, and engineering parameters of the ground can be determined by data log which directly logged to a field computer by the geotechnical engineer on-site, thereby offering quick and preliminary conclusions for design. With proper calibration using full-

scale load testing coupled with soil borings and laboratory testing, the CPT results can be used for final design parameters and analysis (Mayne, 2007).

Land survey tests using cone have major advantages to traditional working methods (soil drilling and laboratory sampling) regarding subsoil investigation because they are rapid, repeatable and economic (Iliesi, 2012). Mechanical and piezocone tests began to be used increasingly often in practice because they are economic methodologies to analyse soil foundation and provide accurate information on some geotechnical parameters (the tip/cone resistance, q_c, sleeve friction, f_s, and in case of CPTu the pore water pressure, u (Sakhawy *et al.*, 2008; Poulsen *et al.*, 2011 and Iliesi, 2012).

1.2 Problem statement

The penetration force to install the sheet pile especially using Press-In method is different for specific site conditions. Therefore, the study is initiated in a hope to determine the penetration force characteristic in clay due to time effect. Using the appropriate penetration force, consumption of material can be reduced if the base material could be built from smaller number of stiffer piles leading to more green construction consisting efficient material cost, environmental impact and time consumption.

Not only for this technology, geotechnical applications such as Statnamic pile testing methods and push-in pile installation techniques have highlighted the need for a better understanding of soil strength performance under high rate of loading. In the case of press-in piles, a correlation between driving force and in-situ soil strength could help to confirm or modify design assumptions (Yusoff, & Black, 2011).

A new Rowe Cell-Vane Shear apparatus has been developed to study the soil shear strength at high speed for clay soils (Yusoff & Black 2011). However, this is a laboratory scale apparatus. Currently, the conventional apparatus is only available for slow rate of loading condition. Therefore, there is a need to innovate and develop current apparatus for actual field condition. For this study, the CPT apparatus were utilized to investigate the rate effect in a real site condition.

To install the pile through hydraulic system, it is crucial to understand the required penetration force needed to do the job. Generally, the penetration force and speed were being different for different soil conditions. Furthermore, there is still a

need to conduct more research to understand the interaction between the piles and the clay behaviour when different speeds are applied to install the piles. Proper understanding of this scenario may facilitate the engineer to mobilize the suitable pile installer to the construction site. Therefore, this study is proposed to investigate the penetration behaviour due to variable penetration speeds.

1.3 Research objectives

The main objectives of this research are:

a) To classify the soil behaviour types by conducting field CPT.
b) To investigate the rate effect by using CPT test for clay soil in RECESS, Batu Pahat by conducting field CPT over a range of rates 0.5 cm/s, 1 cm/s, 2 cm/s, 2.5cm/s, and 5 cm/s.
c) To investigate a relationship between penetration force and rate of installation of clay soils over a range of rates 0.5 cm/s, 1 cm/s, 2 cm/s, 2.5cm/s, and 5 cm/s.

1.4 Scope of Study

This study focuses on the CPT conducted at RECESS UTHM. The sounding of the CPT was conducted up to 9m depth. In addition, five different rates were considered for this test. The apparatus was being able to trigger rate of penetration of 0.5 cm/s, 1 cm/s, 2 cm/s, 2.5cm/s and 5cm/s. The types of soils that be tested in this study is clay soils.

1.5 Significance of Study

The importance of this study is to investigate the time effect of pile penetration force in a full scale geotechnical strength test. A penetration force of the selected sites was investigated of rates of loading 0.5 cm/s, 1 cm/s, 2 cm/s, 2.5 cm/s and 5 cm/s. Then, relationships between basic clay properties with rate of shearing were established.

This knowledge and findings was being capable to establish the relationship between rate effects based on clayey type of soil properties. These findings may serve a wide range of industrial applications whereby require the solution of time domain problems and an associated understanding of rate effects. In addition, it may be used as one of the apparatus for site investigation in predicting of soils behaviour types. It is hope that this study may be a stepping stone for our country to be a technological provider in engineering instrumentations for civil engineering field in a very near future. This was being in line with the Economic Transformation Programme to transform Malaysia into a high-income nation by 2020.

In this research, the rate effects for clayey soils were studied by using a CPT test setup. These findings may serve a wide range of industrial applications whereby require the solution of time domain problems and an associated understanding of rate effects in clay soils. Then, a relationship between basic clay properties with rate of shearing was established.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter elaborate the reviewed document and information needed to support the methodology of the research. There are seven main topics to discuss which are general view of CPT, the existing application of CPT, soil classification by CPT, advantages of CPT, previous case study on rate effect, the engineering properties from CPT, and finally soil engineering properties field test. From the review, the gap of existing method is identified for the proposed method.

2.2 Cone Penetration Test

Recently, researchers have still preferred CPT as the best method to evaluate physical properties of soil (Hamid *et al.*, 2015; Mohammed & El Fatih, 2016). Based from several researches by Kim *et al.* (2006) and Robertson (2010), the CPT has been widely used because it is the most effective in-situ test method for obtaining continuous and reliable soil properties. In addition to that, the standard rate of penetration in a CPT is 20±5mm/s based on the International Reference Test Procedure (IRTP) and the ASTM standard (ASTM D 5778). This standard penetration rate is specified regardless of soil type. Cone penetration at the standard rate is fully drained for clean sand and fully undrained for pure clay. Cone penetration may take place under partially drained conditions at the standard penetration rate, for soils consisting of mixtures of silt, sand and clay, depending on the ratios of these three broad particle size groups (Kim *et al.*, 2006).

The CPT is a field site investigation has many advantages compared to other conventional method available today which are more fast, repeatable and economical. Refers to BS 1377-9:1990, CPT method covers the determination of the resistance of soils in situ to the continuous penetration. CPT has a push rods cone at the base, and can measure continuously or at selected depth intervals the penetration resistance of the cone. If required, the local friction resistance on a sleeve friction and pore pressure near the cone and sleeve. Penetrometer tip with electrical sensors can get all the required data, thereby permitting continuous readings and an instant read-out.

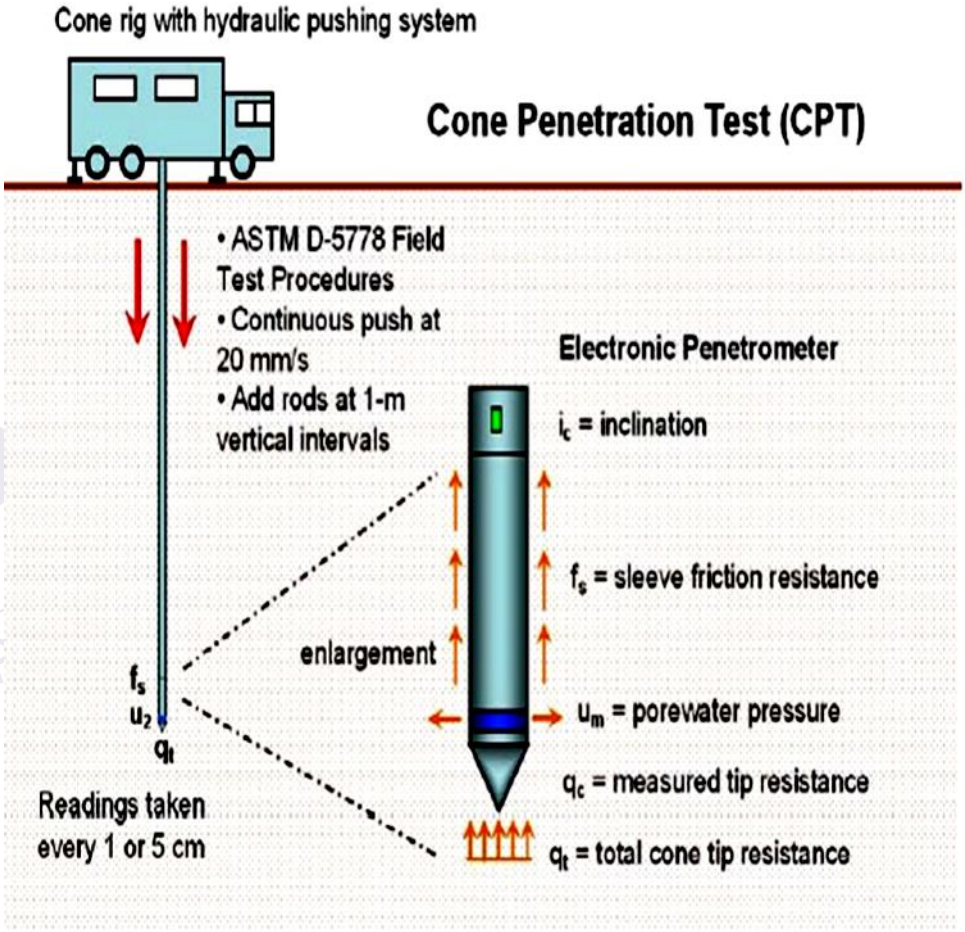

Figure 2.1: Overview of the cone penetration test (ASTM D 5778)

The pushing system for cone penetrometer is currently very common in terms of construction. Many types of vehicles or a specially developed system can be fitted on classical rod seal mounted on a heavy truck. The most frequently heavy systems used to push rods have a capacity between 100 and 200 kN reaching up to 350 kN in

exceptional circumstances. Most common penetration systems can easily reach depths of 30 m but, the maximum penetration depth of the subsoil depends on the geological condition of the site (Iliesi, 2012).

Table 2.1: Basic types of cone penetration tests available for site characterization (Mayne, 2007)

Type of CPT	Acronym	Measurements Taken	Applications
Mechanical Cone Penetration Test	MCPT	q_c (or q_c and f_s) on 20-cm intervals. Uses inner & outer rods to convey loads uphole.	Stratigraphic profiling, Fill control, Natural sands, Hard ground
Electric Friction Cone	ECPT	q_c and f_s (taken at 1- to 5-cm intervals)	Fill placement, Natural sands, Soils above the groundwater table
Piezocone Penetration Test	CPTu and PCPT	q_c, f_s, and either face u_1 or shoulder u_2 (taken at 1- to 5-cm intervals)	All soil types. Note: Requires u_2 for correction of q_c to q_t
Piezocone with Dissipation	CPTù	Same as CPTu with timed readings of u_1 or u_2 during decay	Normally conducted to 50% dissipation in silts and clays.
Seismic Piezocone Test	SCPTu	Same as CPTu with downhole shear waves (V_s) at 1-m intervals	Provides fundamental soil stiffness with depth: $G_{max} = \rho_t V_s^2$.
Resistivity Piezocone Test	RCPTu	Same as CPTu with electrical conductivity or resistivity readings	Detect freshwater - salt water interface. Index to contaminant plumes.

Notes: q_c = measured point stress or cone tip resistance, f_s = measured sleeve friction, u = penetration porewater pressure (u_1 at face; u_2 at shoulder), q_t = total cone resistance, V_s = shear wave velocity.

Referring to Presti (2011), within the electrical cone and piezocone penetration test, there are 3 subcategories of CPT were considered:

i. Electric cone penetration test (CPTe)

This cone penetration can give continuous measurement which is every 2 cm of penetration) of cone resistance, sleeve friction, and in degree of inclination.

ii. The Cone test with pore water pressure (CPTu)

This type of cone penetration is equipment with the additional measurement of pore pressure.

iii. The Seismic Piezocone test (SCPTu)

This piezocone has specialty which has additional possibility of discontinuous measurement of body wave propagation velocities mainly in a down-hole configuration.

2.2.1 Mechanical CPT

In the past few years, mechanical CPT tests began to be used increasingly often in practice because they are economic methodologies to analyse soil foundation and provide accurate information on some geotechnical parameters (the tip/cone resistance, q_c, sleeve friction, f_s. (Iliesi, 2012). Since CPT is only test that can give continous data information to investigated soils, engineers more prefer to use it as in-situ method which is more economical (Robertson, 2010). Based from BS 1377-9:1990, the use of the older type of mechanical penetrometer, where readings are taken through inner push rods thrusting against load capsules mounted on the thrust machine should be noted that it does not give precisely the same readings as would be obtained by the electrical penetrometer tip, which is specified as standard.

2.2.2 Electronic CPT

Essentially, the electric cone penetrometer consists, of two strain gauge load cells which is one being attached to the cone tip and measuring cone tip resistance, q_c. The other strain gauge load cells connected to the other side, of the cone penetrometer and measuring sleeve friction, f_s. The cone tip resistance, q_c, is defined as the total force acting on the cone tip, F_c, divided by the cross-sectional area of the base of the cone, A_b, and is usually expressed in units of MPa. The sleeve friction, f_s, is defined as the total force on the friction sleeve, F_s, divided by the surface area of the sleeve, A_s, and is usually expressed in units of kPa (Jaksa *et al.*, 2000).

Additionally, (Rogers, 2006) said that one of the advantageous of electric cone has their own temperature sensor that very useful in assessing the precise position of the zone or zones of saturation, which are of great import in slope stability and consolidation studies. The electric CPT is shown in Figure 2.2.

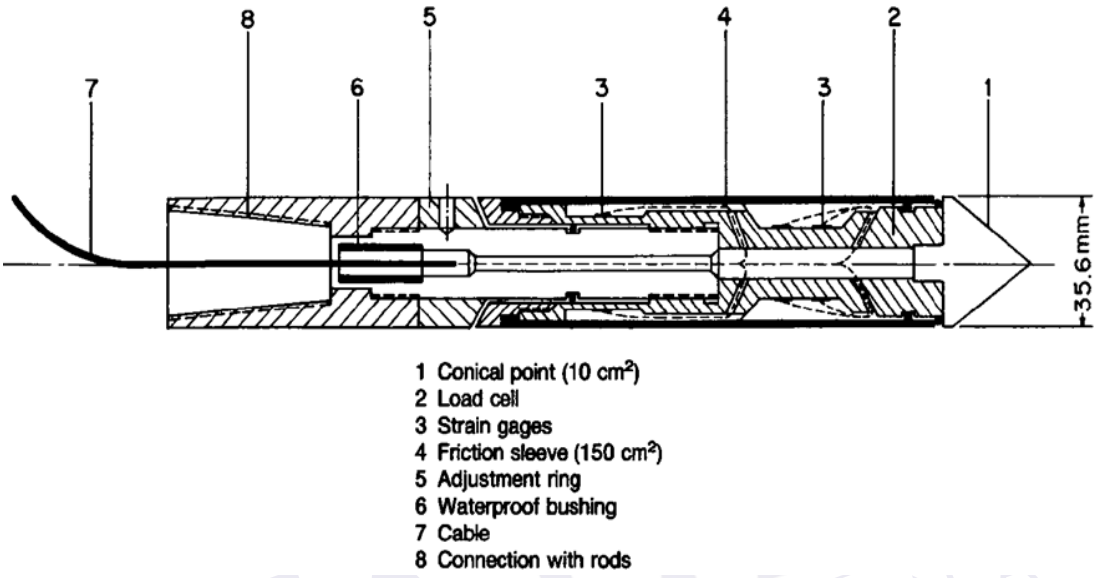

Figure 2.2: Electric CPT (ASTM D 5778-95)

2.2.3 Electric Piezocone

Electric Piezocone (CPTu) is the premier soil logging tool. The CPTu provides a rapid, reliable and economic means of determining soil stratigraphy, relative density, strength and equilibrium groundwater pressures. CPTu offers a choice of cones with varying tip (q_c) capacities, sleeve friction (f_s) and pore pressure transducers (U). Pore pressure can be measured at one of 2 locations, either on the face of the cone tip or behind the cone tip. Pore pressure dissipation data is recorded automatically during pauses in penetration. All data is displayed in real time, facilitating the on-site decision making process. Field data reduction, plotting and CPT interpretation can be carried out upon request. Cone penetration test with pore water pressure with its components can be refers as in Figure 2.3.

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